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SECURITY CLASSIFICATION OF THIS PAGE

DTIC FILE COPY

(1)

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

AD-A199 198

1b. RESTRICTIVE MARKINGS	
2b. DECLASSIFICATION	3. DISTRIBUTION/AVAILABILITY OF REPORT DISTRIBUTION A:
4. PERFORMING ORGANIZATION REPORT NUMBER(S)	5. MONITORING ORGANIZATION REPORT NUMBER(S)
6a. NAME OF PERFORMING ORGANIZATION Heat Research Division	6b. OFFICE SYMBOL (If applicable) SGRD-UE-HR
7a. NAME OF MONITORING ORGANIZATION	
6c. ADDRESS (City, State, and ZIP Code) Kansas Street Natick, MA 01760-5007	7b. ADDRESS (City, State, and ZIP Code)
8a. NAME OF FUNDING/SPONSORING ORGANIZATION USARIEM	8b. OFFICE SYMBOL (If applicable)
9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER	
8c. ADDRESS (City, State, and ZIP Code)	10. SOURCE OF FUNDING NUMBERS PROGRAM ELEMENT NO. / PROJECT NO. / TASK NO. / WORK UNIT ACCESSION NO. 129

11. TITLE (Include Security Classification)

Environmental FActors: Acclimatization:Transporting Athletes into Unique Environments

12. PERSONAL AUTHOR(S)

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13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15. PAGE COUNT
Journal Article	FROM Jun 88 TO Jun 88	14 July 1988	13

16. SUPPLEMENTARY NOTATION

17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB-GROUP	Heat, Altitutde, Cold, Air Pollution Acclimatization, Physical Training

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

The human body does not successfully acclimatize to all environmental stresses. Therefore, the purpose of this article is to summarize the physiological changes which athletes can (or cannot) make, when exposed to high terrestrial altitude, air pollution, cold, and heat. This article will also present an overview of strategies which may be used during training and competition, to counteract these environmental insults.

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT ☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT. ☐ DTIC USERS	21. ABSTRACT SECURITY CLASSIFICATION
22a. NAME OF RESPONSIBLE INDIVIDUAL Lawrence E. Armstrong, PH.D	22b. TELEPHONE (Include Area Code) / 22c. OFFICE SYMBOL

DD Form 1473, JUN 86 Previous editions are obsolete.

SECURITY CLASSIFICATION OF THIS PAGE
UNCLASSIFIED

88 9 8 040

Series Title: ENVIRONMENTAL FACTORS

ACCLIMATIZATION: TRANSPORTING ATHLETES INTO UNIQUE ENVIRONMENTS

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There are many sports in which athletes compete in a variety of environments during the course of a season. In the National Football League, for example, the season begins during the hottest months of the year, but ends when temperatures are below freezing. An NFL team could conceivably play in hot, humid Miami and in frigid Green Bay, on successive weekends. In addition, professional football players who train at sea level are forced to make extreme physiological adaptations when they attempt to compete at high altitudes--such as the Mile High Stadium in Denver, Colorado.

Triathletes and long distance runners who travel to the Los Angeles Marathon (air pollution), to the Pike's Peak Marathon (altitude), or to Hawaii's Ironman Triathlon (hot, humid), also expose their bodies to environmental stresses for which they may be unprepared. Even indoor sports are not exempt from this problem. In recent years, National Basketball Association teams that competed against the Boston Celtics during playoff games, found the Boston Garden to be oppressively hot and humid. This "sixth man" was an advantage for the home team, which had played in that environment many times before. High school track and field coaches face a similar problem during winter months. Athletes who train outdoors may not be physically prepared for the heat and humidity of indoor tracks.

When exposed to changes in environments, the human body makes compensatory adjustments. These adjustments involve essentially all organs of the body, in an attempt to maintain body temperature, oxygen and fuel delivery to cells, and removal of waste products. If these adjustments progress with the duration of exposure, a state of acclimatization is reached. Acclimatization to a given environment offers greater stability of body systems and a better chance of survival. Acclimatization and physical training have two goals in common: (1)

to reduce the physiological strain experienced by athletes, and (2) to allow athletes to compete as though they were in a neutral environment.

But the human body does not successfully acclimatize to all environmental stresses. Therefore, the purpose of this article is to summarize the physiological changes which athletes can (or cannot) make, when exposed to high terrestrial altitude, air pollution, cold, and heat. This article will also present an overview of strategies which may be used during training and competition, to counteract these environmental insults. A complete coverage of these four factors will appear in the Journal of Applied Sports Science Research, volume —, — 1988.

ALTITUDE

When travelling to competition at altitudes above 3,000 ft, athletes experience inadequate delivery of oxygen to working muscles. Hyperventilation (increased breathing rate) and major discomfort during exercise first occur in unacclimatized individuals, at an altitude of 3,000 ft. Above 5,000 ft, maximal oxygen consumption (VO_2max) decreases approximately 3% per 1,000 foot increase in altitude. At an altitude of 7,500 ft, the mile run time slows by 5-10 seconds per mile. However, high intensity, short-term power events (especially less than 2 minutes in length) are generally not influenced greatly. For example, in both the 1953 Pan American Games and the 1968 Olympics (both conducted at altitude), world records were broken in running events of 400 meters and less.

These symptoms should not suggest that residence at altitude is impossible, however. An estimated 45 million people live at altitudes greater than 10,000 ft. In fact, the act of living and training at altitude results in physiological adaptations which, as a unit, are named altitude acclimatization. These adaptations primarily involve hyperventilation (increased breathing rate), increased

hemoglobin concentration, increased muscle capillary density, and increased myoglobin concentration in muscle. These adaptations increase the amount of oxygen carried by the blood, the delivery of blood to working muscles, and the retention of oxygen in muscle cells.

Three to four weeks are required for most acclimatization adaptations to occur. However, altitude acclimatization rarely allows athletes to fully regain their full sea level abilities. One research study, conducted at 13,000 ft, reported that 12 days of altitude training resulted in a 45% increase in endurance capacity (compared to day 1 at altitude); after 16 days, a 60% increase in endurance capacity was measured. It appears that the only certain way to regain full exercise capacity is to return to sea level. Although it is widely held that previous altitude training improves performance at sea level, it has not been demonstrated that highly trained athletes will experience significant improvements.

Breathlessness, headache, nausea, difficulty in sleeping, weakness, and dizziness may be observed upon arrival at high altitude (over 7,200 ft). This is especially true if the ascent is rapid. Altitude acclimatization and some medications reduce the incidence of these symptoms. Altitude sickness may be related to these facts: (a) blood plasma volume decreases noticeably (-11% to -22%), (b) body fluid shifts occur, and (c) dehydration is common, in the first 3 - 12 days of high altitude exposure.

AIR POLLUTION

Like high altitude, air pollutants may reduce oxygen delivery to working muscles, by acting at various anatomical sites. The three air pollutants which have been shown to have physiological consequences are carbon monoxide, ozone, and the sulfur oxides.

Carbon monoxide, which is a colorless/odorless by-product of vehicle emissions, impairs oxygen delivery by binding with hemoglobin (on red blood cells), in place of oxygen. In fact, the affinity of hemoglobin for carbon monoxide is 230 times greater than for oxygen. Several studies have demonstrated a decrease in VO_2max with increased blood levels of carbon monoxide. Also, exposure to carbon monoxide in excess of 27 parts per million (ppm) for 1 hour, can result in partial loss of vision and impaired judgement. In comparison, carbon monoxide levels in the United States average 15 - 25 ppm in many cities, but can reach 50 ppm on hot, windless days. Significant carbon monoxide fumes may extend as far as 65 ft on either side of a busy street.

Ozone (a product of hydrocarbons, ultraviolet light and nitrogen dioxide) constricts the bronchial tubes that supply air to the lungs. This makes breathing difficult during exercise of moderate intensity, but these effects are worst during a maximal effort. Other symptoms include eye irritation, coughing, and a feeling of nausea.

Sulfur oxides are by-products of fossil fuel combustion. They irritate the upper respiratory tract, and result in decreased performance during submaximal exercise performed by asthmatics. No studies have investigated the effect of sulfur oxides on maximal or near-maximal performance. Seoul, Korea, the site of the 1988 Summer Olympics, is known to have high levels of sulfur oxide pollution.

Acclimatization to air pollution has not been documented, although the airways evidently become desensitized to ozone and to the sulfur oxides. The physiological effects are much less severe after 2 - 5 days of exposure to these two compounds. Other air pollutants (i.e. nitrogen dioxide, particulates, peroxyacetyl nitrate) have not been studied extensively. Further research is required to clarify their effects on physical performance and the body's ability to acclimatize to these compounds.

COLD

Although scientists have debated for decades whether cold acclimatization is possible or not, the most recent review articles indicate that it is possible, but that physiological adaptations are subtle. This debate has occurred because the extent of cold acclimatization depends on the temperature of the air at the skin surface, and because many previous studies did not expose subjects to adequate cold stimuli.

The body has two methods of maintaining body heat during cold acclimatization: metabolic and insulative. These involve increased metabolic heat production via shivering, and decreased heat loss via reduced blood flow to skin, respectively. Different modes of cold acclimatization are observed when subjects are exposed to different forms of cold stimuli (i.e. cold water vs cold air).

Behavioral responses in cold environments, however, are of greater thermoregulatory significance than these subtle physiological adaptations. Such behavioral responses include (a) using external heat, (b) limiting cold exposure time, (c) reducing the surface area which dissipates heat, (d) adding clothing, and (e) increasing internal heat production via exercise. These last two items interact, in that exercise intensity and duration are important determinants of the amount of clothing required for personal safety and comfort in the cold.

HEAT

During repeated days of exercise-heat exposure, the human body acclimatizes. Internal temperature and heart rate decrease, while blood plasma volume and sweat rate decrease. Several other adaptations to heat may be found in Table 2. The function of these physiological adaptations is to improve heat transfer from the body's core to its periphery, and ultimately to the external environment. If heat is not transferred to the surroundings, it will be

Table 2

stored and exercise performance will diminish because of hyperthermia (elevated body temperature).

Heat acclimatization requires 1.5 - 2.0 hours of exercise for 10 - 14 days. The goal of this training is to elevate internal temperature to a safe level (100.6 - 102.2°F) and maintain it, utilizing exercise which is greater than 50% VO_2max. Mere heat exposure (i.e. sitting in a sauna) may induce partial heat acclimatization, but it cannot be expected to match the results gained by exercise in the heat.

If an athlete acclimatizes to a hot-dry environment, but then moves into a hot-wet environment, he/she should acclimatize to the hot-humid conditions before attempting competition or strenuous training. If an athlete leaves a hot environment to train in cool conditions, he/she can maintain heat acclimatization adaptations for 1 - 4 weeks.

Two heat illness varieties are favorably affected by heat acclimatization. Heat syncope (fainting) results from pooling of blood in the skin or legs, and insufficient return of blood to the heart and brain. Heat syncope occurs most often during the first 5 days of heat exposure, but the cardiovascular adaptations which occur during the first 3 - 5 days of heat acclimatization (i.e. blood volume expansion, heart rate reduction) result in a rapid decline of fainting episodes. Heat exhaustion, the most common form of heat illness among athletes, is diagnosed by a variety of signs and symptoms. These include "heat sensations" on the head or torso, chills, abdominal cramps, "goose flesh", elevated resting heart rate, dizziness, nausea, and extreme weakness. Heat acclimatization reduces the symptoms of heat exhaustion by more than 50%, probably because of the improved cardiovascular stability which is gained.

ACCLIMATIZATION STRATEGIES

When training at high altitudes, athletes should ascend slowly, ascend in stages, avoid dehydration, and avoid over-exertion during the initial days. When competing at high altitudes (such as the 7,300 ft. elevation of Mexico City at the 1968 Olympics), there are three acclimatization strategies which have been utilized. First, athletes arrive at the stadium just hours before competition, trying to avoid the negative physiological changes. Second, athletes live and train at high altitude for 2-4 weeks prior to competition, trying to acclimatize. Third, athletes live and train at intermediate altitudes (i.e. 3,000 - 5,000 ft) for 1 - 3 weeks, and later move to higher elevations (i.e. 7,300 ft). The goal of this strategy is to perform workouts of greater intensity and duration at intermediate elevations, yet encourage preliminary altitude adaptations to occur.

Although acclimatization to air pollution has not been documented, desensitization probably occurs to the sulfur oxides and ozone. However, avoiding high levels of air pollutants is wise. Athletes should plan workouts to avoid periods of peak smog, to avoid locations which are high in pollutants, and to reduce exercise intensity and duration. Exercising in parks or along a beach, where offshore breezes whisk pollutants away, is a sound practice. It is also wise to cancel competition or training when pollution reaches critical levels.

Cold acclimatization is directly related to the air temperature at the skin surface. Athletes may exercise in cold environments, but may never require acclimatization to cold because their skin is covered by clothing. In extremely cold surroundings, three layers of clothing should be worn, to protect the skin from frostbite: an inner thermal layer (wool or polypropylene), a middle insulating layer (fiber-filled vests), and an outer wind-resistant layer (nylon or Gore-Tex). When exercise-induced heat storage increases to the point that an athlete overheats, layer(s) should be removed. Athletes also should recognize that a layer of clothing loses its insulative properties when it becomes sweat-

soaked. Because the wind chill index involves two factors (wind speed and air temperature), it is best combatted by altering clothing to the dominant factor. At -40°F and 5 mph wind speed (wind chill = -47°F), cold-proof clothing is in order. At -10°F and 15 mph (wind chill = -45°F), wind-proof clothing should be worn. Utilizing wind direction to determine the path of an outdoor training session is also prudent.

Intense training in a cool environment enhances heat tolerance, but cannot replace hot-weather training. To induce optimal heat acclimatization, the total exposure time in the heat, and the exercise intensity, should be gradually increased for 10 - 14 days. If conditions are severe, it is likely that athletes will not be able to complete interval workouts which were previously completed in cooler environments. For this reason, the author recommends that intense interval training be done in milder environments. Exercise-heat exposure (duration and intensity) should begin at easy-to-moderate levels and should be increased in stages. Monitoring of rectal temperature will insure that body temperatures are maintained within safe limits (e.g. 100.6 - 102.2°F). In the northern United States, it has been demonstrated that highly trained athletes do not require heat acclimatization to safely withstand training in mid-summer conditions.

ACKNOWLEDGEMENTS

Dr. John Patton, Mr. Charles Fulco, Mr. Peter Frykman, Dr. Allen Cymerman, and Dr. Murray Hamlet assisted in the collection of information for this article.

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Table 1 - The effect of altitude on symptoms and maximal oxygen consumption (VO_2max). Redrawn from Balke (ref. 5) and Luft (ref. 8).

Altitude		Symptoms *		Percent Change in VO_2max
(feet)	(meters)	At Rest	At work	
0	0	—	—	0 %
3281	1000	—	—	-3 %
6562	2000	—	A	-7 %
10171	3100	A	A	-17 %
14108	4300	B	C	-28 %
18374	5600	C	D	-42 %
22967	7000	D	E	-53 %
29529	9000	F	F	—

* - A moderate difficulty in breathing
B lightheadedness, nausea, restlessness, labored breathing
C headache, tiredness, food repulsion, very difficult breathing
D lethargy, disturbed judgement, general weakness approaching unconsciousness
E inability to maintain minimum effort
F death

Table 2 - Adaptations which occur during heat acclimatization.

Measurement	Response
heart rate	decrease
rectal temperature	decrease
skin temperature	decrease
sweat sodium conc.	decrease
RPE *	decrease
fatigue	decrease
syncope (fainting)	decrease
blood plasma volume	increase
sweat rate	increase
work capacity	increase

* - rating of perceived exertion, a psychological measurement of difficult of effort